

MEASUREMENT AND PREDICTION OF MAXIMAL SHIVERING CAPACITY IN HUMANS

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INTRODUCTION

Shivering is a well-recognized mechanism for the maintenance of core body temperature (T_{co}) in response to cold exposure. Cold-water immersion studies in our laboratory have demonstrated that pharmacologic inhibition of shivering causes an increase in the rate of core cooling (unpublished data), an increased T_{co} afterdrop and attenuation of the rate of rewarming (1). The duration that shivering can be maintained before onset of fatigue may be an important determinant of survival time. However, in the assessment of shivering endurance, it would be useful to first quantify the maximal shivering response attainable and to determine predictive variables for this response.

Iampietro et al. (2) assessed metabolic work due to shivering in 16 humans exposed to cold air. The highest response was 5 times the resting metabolic rate and approximately 50% of maximal VO_2 . These values are currently used in mathematical models of shivering metabolism (3). However, they have limitations in their applicability to maximal shivering responses: the experiments were only 30 min long; the greatest cold stress was only $-7^{\circ}C$ air; and no measurements of skin temperature (T_{sk}) or T_{co} were obtained.

The purpose of the study was to develop a protocol to elicit maximal shivering intensity in humans and to determine which factors may be used to consistently predict this shivering response. Based on the parabolic relationship between shivering intensity and T_{sk} , with a maximal response at a T_{sk} of about $20^{\circ}C$ (4), we hypothesized that the combination of low T_{co} ($-35^{\circ}C$) and a T_{sk} of $20^{\circ}C$ would elicit the maximal shivering response.

METHODS

We completed studies on 16 subjects (12 males, 4 females) (mean SD: age = 24.9 ± 6 years; height = 176 ± 9 cm; weight = 76.1 ± 9 kg; body fat = $21.3 \pm 5\%$ and $VO_{2max} = 51.8 \pm 10$ ml·kg⁻¹·min⁻¹) after they gave informed consent. Core temperature was measured in the esophagus (T_{es}). T_{sk} and heat flux measurements were obtained by 12 thermal flux transducers attached to the forehead, chest, abdomen and extremities according to previous protocols (5). ECG, heart rate (HR) and blood pressure (BP) were monitored throughout the study. Metabolic and respiratory parameters were also measured with a Vmax 229 system (Sensor Medics).

Subjects were studied on 2 separate days. On one day, maximal exercise capacity ($\text{VO}_{2\text{max}}$) was determined. On the cold water immersion day, subjects sat quietly for 10 min of baseline measurements. They were then immersed in 20°C water. Water temperature (T_w) was then lowered to 8°C over 15 min by adding ice. After 60 to 70 min of immersion, T_w was then raised at 0.8°C/min to 20°C. T_w was maintained at this temperature until shivering metabolism consistently decreased and T_{es} increased. Subjects were then transferred to 40°C water for rewarming. The trial was terminated when T_{es} reached 37.0°C.

The maximal observed shivering response was determined and expressed in absolute (Absolute Shiv_{max}) and relative (Relative Shiv_{max}) terms. A stepwise regression was then performed, using height, weight, percent body fat, body mass index, absolute $\text{VO}_{2\text{max}}$ and relative $\text{VO}_{2\text{max}}$ as predictors for Absolute Shiv_{max} and Relative Shiv_{max} . A best-fit equation was then developed for predicting maximal shivering.

RESULTS

The average prewarming VO_2 reached a value of $14.4 \pm 5.9 \text{ ml} \cdot \text{O}_2 \cdot \text{kg}^{-1} \cdot \text{min}^{-1}$. Relative Shiv_{max} reached an average value of $21.5 \pm 4.6 \text{ ml} \cdot \text{O}_2 \cdot \text{kg}^{-1} \cdot \text{min}^{-1}$. This value corresponded to 41.5% of $\text{VO}_{2\text{max}}$ and 4.7 times resting baseline values. In all subjects, shivering was rapidly extinguished with a return of VO_2 to baseline levels upon transfer to 40°C water.

Data from 1 subject was not included in the prediction equations because his body mass index (BMI) was 3 SDs above the group mean and his $\text{VO}_{2\text{max}}$ was 2 SDs below the group mean. Although percent fat was significantly correlated to Absolute Shiv_{max} , the best-fit formula for predictions included $\text{VO}_{2\text{max}}$ and BMI values as follows:

Relative $\text{Shiv}_{\text{max}} = 0.339 (\text{Relative } \text{VO}_{2\text{max}}) - 0.951 (\text{BMI}) + 26.2$ (1)
(adjusted $r^2 = 0.726$, $\text{SEE} = 2.195$, $P = 0.0003$); and

Absolute $\text{Shiv}_{\text{max}} = 0.331 (\text{Absolute } \text{VO}_{2\text{max}}) - 0.056 (\text{BMI}) + 1.6$ (2)
(adjusted $r^2 = 0.727$, $\text{SEE} = 0.156$, $P = 0.0004$).

DISCUSSION

In the present protocol, the peak observed shivering metabolism in mildly hypothermic human subjects reached an average of 4.7 times the resting metabolic rate and peaked at $21.5 \pm 0.5 \text{ ml } \text{O}_2 \cdot \text{kg}^{-1} \cdot \text{min}^{-1}$. The unique feature of this protocol is that the high shivering metabolism at a significantly decreased core temperature was increased further when T_{sk} was increased to -20°C. Because other factors, such as rate of change in T_{sk} , also affect shivering intensity, the maximum possible shivering intensity may not have been reached. It is understandable that both prediction equations include $\text{VO}_{2\text{max}}$ measures and BMI.

Greater aerobic capacity would indicate greater shivering capacity, while the negative correlation between BMI and maximal shivering intensity is consistent with the inverse relationship between shivering intensity **and** body fatness at a given skin temperature (6).

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